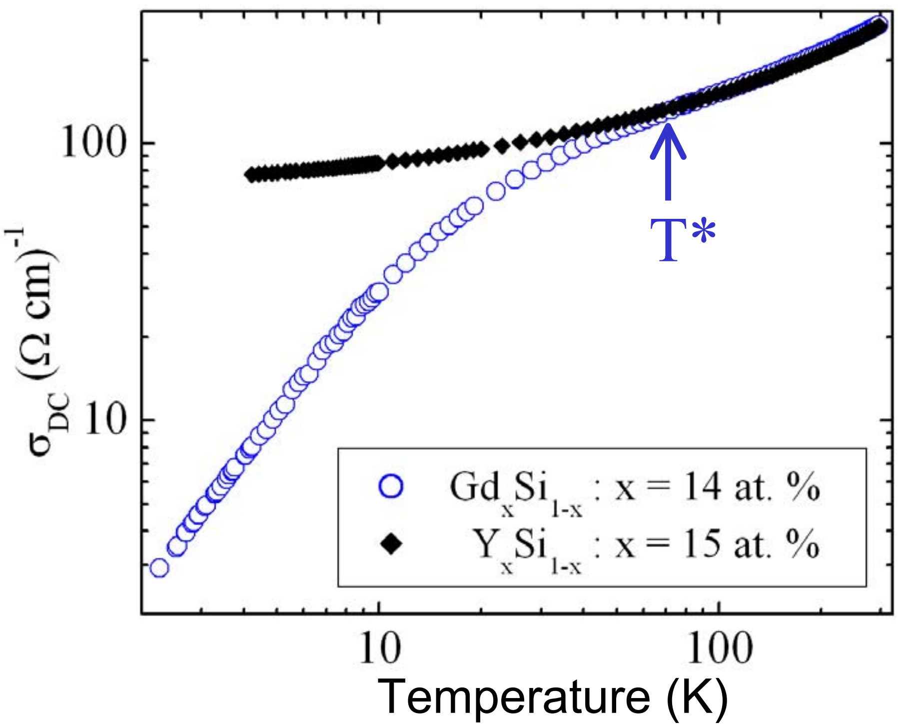
Local and Non-Local Magnetic Moments in Semiconductors

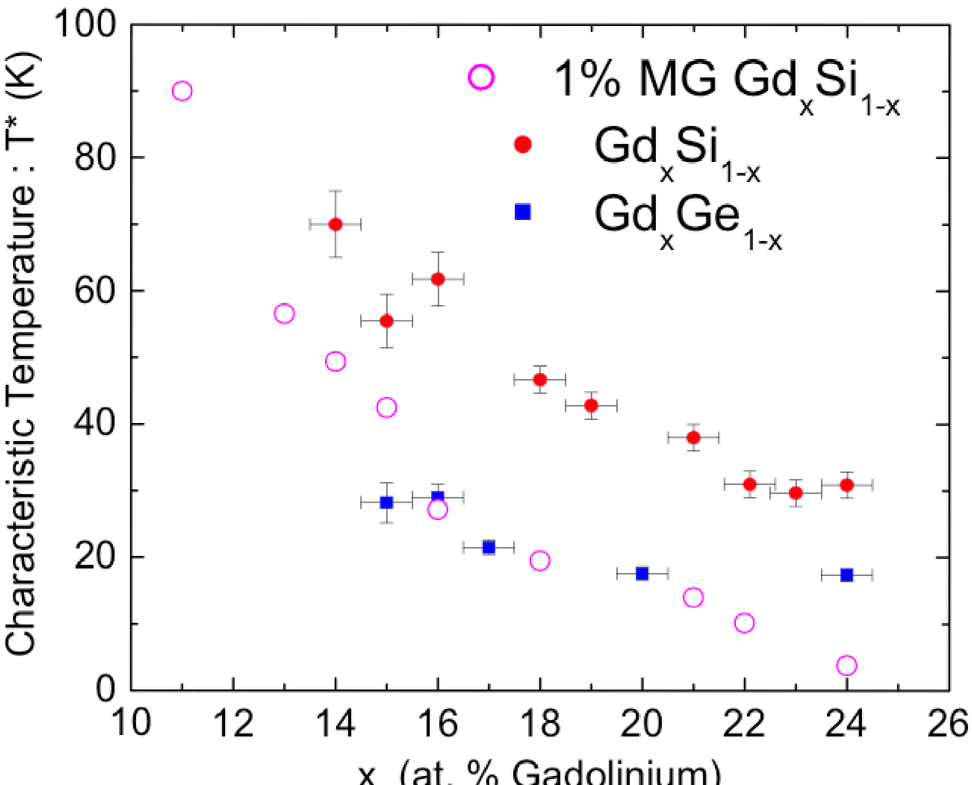
Frances Hellman, UCSD, DMR-0203907

The effects of adding magnetic moments such as Gd to semiconductors such as Si are enormous

Below a characteristic temperature T*, the conductivity of amorphous Gd-Si deviates substantially below Y-Si and develops huge negative magnetoresistance MR = -magnetoconductance MG

T* and MG *decreases* with *increasing* Gd concentration and with decreased band gap (Gd-Ge vs Gd-Si), signs that T* is due to an onset of electron correlation effects





1) Adding magnetic atoms to semiconductors causes the semiconductor to become extremely sensitive to a magnetic field, which it normally is not. Currently, these effects only become important at a temperature called T* which is below room temperature. We are trying to understand what controls T*. If we could increase T* to room temperature or above, there would be applications for this material (for example, a transistor which could be turned on and off with a magnetic field instead of an electric field, allowing it to be switched without electric contact.) Also, the size of the effects we see below T* suggest strongly that we will learn something really new about the physics of how electrons move and interact with each other in materials. We understand very well how electrons move and interact with each other in a vacuum, but much less well when they are in a solid material, particularly materials where magnetic moments are present. The data above shows (left side) how we define T*, which is the temperature where the magnetically doped Gd-Si deviates from the non-magnetically doped Y-Si. The right side shows the result that T* and the large effects of the magnetic field which occur below T* are reduced when we add more magnetic atoms, which is not what we originally expected but for which we now have a model, and are reduced by substituting Ge for Si. These results point us clearly towards our next experiments: using C instead of Si, which should both increase T* and confirm our model for what controls T*.

2) For the physics audience: T* is the temperature below which the magnetic moment of the Gd dopant affects the conductivity. On applying a magnetic field, the conductivity of the Gd-Si increases; the increase depends exponentially on temperature, becoming enormous at low temperatures (many orders of magnitude change). The “1% MG” data shown in the figure is the temperature below is the highest temperature which shows a significant negative magnetoresistance, defined as a 1% change. The fact that T* and the 1% MG temperature are correlated so strongly with each other shows they are connected, as expected. The fact that both decrease with increasing Gd concentration is opposite to simple expectations of the effects of introducing magnetic moments; simple models would predict either no dependence or an increased temperature with increased concentration of Gd. We have also shown that adding non-magnetic Y causes T* to decrease, similarly to adding Gd. The decrease signifies that more complex physics is involved, specifically that the electron concentration is the most important determination of T*, not the Gd concentration. This suggests in turn that electron screening must be playing a crucial role, most likely related to formation of the Coulomb gap which is influencing the electron-local moment interaction which produces the large magnetoresistance.

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Education and Outreach: Two graduate students (Barry Zink and Li Zeng), a post-doctoral associate (Erik Helgren) and many undergraduate research students (in the past year, Bryna Hazelton, Krista Adams, Nareg Sinenian, Kevin McCarthy, Ed Wu) contributed to this work.

Bryna and Ed won undergraduate research awards for their work; both are now attending graduate school. Nareg and Kevin graduate in '05. They all presented results at undergraduate research conferences.

Barry Zink completed his PhD ("Specific Heat and Thermal Conductivity of Thin Film Amorphous Magnetic Semiconductors") and received an NRC post-doctoral fellowship award.

Li Zeng is a 2nd year graduate student.

Erik Helgren is a post-doctoral associate still working in my group (recently promoted to project scientist as a tribute to his talents and abilities).

PI Hellman gave two public lectures **Magnets: Science, Technology, and "Magic Tricks"!!** during this past year (in Boulder and Boston). She is an active member of the Physics Community, serving on many boards and committees

Societal Impact:
Semiconductors have contributed profoundly to both modern technology and to our fundamental understanding of basic electronic processes because they are so sensitive to added impurities like P, temperature, strain, etc. By adding magnetic impurities such as Gd, we make them sensitive also to magnetic field, which provides new opportunities for basic studies of electro-magnetic processes as well as introducing the possibility of new types of devices which switch by application of magnetic field instead of electric voltage.